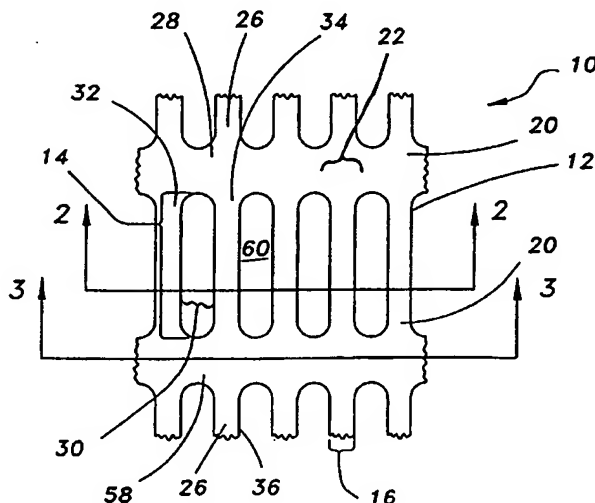




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<b>(21) International Application Number:</b> PCT/US98/25654 <b>(22) International Filing Date:</b> 3 December 1998 (03.12.98)  <b>(30) Priority Data:</b> 08/984,307      3 December 1997 (03.12.97)      US  <b>(71) Applicant:</b> PPG INDUSTRIES OHIO, INC. [US/US]; 3800 West 143rd Street, Cleveland, OH 44111 (US).  <b>(72) Inventors:</b> NEUBAUER, Jeffrey, A.; 1355 Terrace Drive, Pittsburgh, PA 15228 (US). NOVICH, Bruce, E.; 1035 Highmont Road, Pittsburgh, PA 15232 (US). RAGHUPATHI, Narasimhan; 3978 Murry Highland Circle, Murrysville, PA 15668 (US).  <b>(74) Agents:</b> SIMINERIO, Andrew, C.; PPG Industries, Inc., One PPG Place, Pittsburgh, PA 15272 (US) et al.		<b>(81) Designated States:</b> AU, BR, CA, CN, JP, KR, MX, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>

(54) Title: REINFORCED POLYMERIC GEOGRIDS



## (57) Abstract

The present invention provides geogrids (10) for reinforcing soil material which include a first plurality of spaced-apart generally parallel members (12) comprising a thermoplastic matrix material (44) reinforced with fibers (46) having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material (44); and a second plurality of spaced-apart generally parallel thermoplastic members (58) positioned adjacent to and forming a plurality of intersections (26) with at least a portion of the first plurality of strands (12), wherein average thickness of an intersection (26) of the plurality of intersections is greater than average thickness of a corresponding member of the first plurality of members (12) which is adjacent to the intersection (26).

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## **REINFORCED POLYMERIC GEOGRIDS**

### **Field of the Invention**

This invention relates generally to geosynthetic materials for erosion  
5 control and soil reinforcement and, more specifically, to a reinforced geogrid  
having intersecting members in which at least a portion of the intersections of  
the members have an average thickness which is greater than the average  
thickness of at least one of the adjacent members.

### **Background of the Invention**

10 Geosynthetic materials provide reinforcement in numerous  
geotechnical engineering applications, such as bulk soil reinforcement,  
separation of soil layers, soil filtration, drainage control, erosion control and  
vegetation support. However conventional polymeric geosynthetic materials,  
15 such as geogrids, are subject to undesirable elongation and creep under  
sustained tensile load. Depending upon the orientation of the tensile load  
with respect to the geosynthetic material, creep can occur along the  
longitudinal, transverse or both directions of the geosynthetic material.  
Creep resulting in 5 to 10 percent or more elongation of polymeric  
20 geosynthetic material is not uncommon, even at tensile loads which are only  
about 20 to 50 percent of the short term ultimate strength of the polymeric  
geosynthetic material.

Another drawback of polymeric-based geosynthetic materials is that  
the weight per unit area is substantial, particularly for materials designed to  
25 withstand heavy loads, making such materials challenging to transport and  
install. Also, the density of polymeric-based geosynthetic materials is  
generally less than that of saturated soil, which contributes to movement of  
the geosynthetic when installed in soil saturated with water.

Despite the foregoing, most engineering geogrids in widespread use  
30 today are made from polymeric materials. For example, U.S. Patents Nos.

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4,374,798; 4,756,946; 5,156,495 and 5,419,659 disclose uniaxially and biaxially-oriented geogrids formed by stretching a plastic material having depressions or holes to provide intersections of greater thickness than adjacent connecting strands.

5       A reinforced geosynthetic material is needed which is resistant to elongation and creep, has a density closer to that of soil and has lower weight per unit area than a similarly configured geogrid formed from polymeric materials alone.

10                                   **Summary of the Invention**

      The present invention provides a geogrid for reinforcing soil material, the geogrid comprising: (a) a first plurality of spaced-apart generally parallel members comprising a thermoplastic matrix material reinforced with fibers having a predetermined deformation temperature which is greater than a  
15   predetermined deformation temperature of the thermoplastic matrix material; and (b) a second plurality of spaced-apart generally parallel thermoplastic cross-members positioned adjacent to and forming a plurality of intersections with at least a portion of the first plurality of strands, wherein average  
20   thickness of an intersection of the plurality of intersections is greater than average thickness of a corresponding member of the first plurality of members which is adjacent to the intersection.

      Another aspect of the present invention is a geosynthetic composite comprising: (a) a geogrid for reinforcing soil material, the geogrid comprising:  
25   (i) a first plurality of spaced-apart generally parallel members comprising a thermoplastic matrix material reinforced with fibers having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material; and (ii) a second plurality of spaced-apart generally parallel thermoplastic cross-members positioned adjacent to and forming a plurality of intersections with at least a portion of  
30   the first plurality of strands, wherein average thickness of an intersection of

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the plurality of intersections is greater than average thickness of a corresponding member of the first plurality of members which is adjacent to the intersection; and (b) a second geosynthetic material coextensive with at least a portion of and positioned adjacent to a side of the geogrid, wherein the  
5 second geosynthetic material is different from the geogrid.

Yet another aspect of the present invention is a reinforced soil composite comprising: (a) soil material; and (b) a geogrid for reinforcing the soil material to form a reinforced soil composite, the geogrid comprising: (i) a first plurality of spaced-apart generally parallel members comprising a  
10 thermoplastic matrix material reinforced with fibers having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material; and (ii) a second plurality of spaced-apart generally parallel thermoplastic cross-members positioned adjacent to and forming a plurality of intersections with at least a portion of  
15 the first plurality of strands, wherein average thickness of an intersection of the plurality of intersections is greater than average thickness of a corresponding member of the first plurality of members which is adjacent to the intersection.

#### 20 Brief Description of the Drawings

The foregoing summary, as well as the following detailed description of the preferred embodiments, will be better understood when read in conjunction with the appended drawings. In the drawings:

Fig. 1 is a top plan view of a reinforced geogrid according to the  
25 present invention;

Fig. 2A is a cross-sectional view of the reinforced geogrid of Fig. 1, taken along line 2-2 of Fig. 1;

Figs. 2B, 2C and 2D are cross-sectional views of alternative embodiments of reinforced geogrids according to the present invention;

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Fig. 3a is a cross-sectional view of the reinforced geogrid of Fig. 1, taken along line 3-3 of Fig. 3;

Fig. 3b is a cross-sectional view of an alternative embodiment of a reinforced geogrid according to the present invention;

5 Fig. 4 is a cross-sectional plan view of an alternative embodiment of a reinforced geogrid according to the present invention;

Fig. 5 is a top plan view of an alternative embodiment of a reinforced geogrid of the present invention;

10 Fig. 6 is a top plan view of an alternative embodiment of a reinforced geogrid of the present invention;

Fig. 7 is a cross-sectional view of the reinforced geogrid of Fig. 6, taken along line 6-6 of Fig. 7;

Fig. 8 is a cross-sectional view of an assembly including a reinforced geogrid according to the present invention;

15 Fig. 9 is a cross-sectional view of an alternative embodiment of an assembly including a reinforced geogrid according to the present invention;

Fig. 10 is a cross-sectional view of a side elevation of a soil slope reinforced with a geogrid according to the present invention;

20 Fig. 11 is a cross-sectional view of a side elevation of a landfill reinforced with a geogrid according to the present invention; and

Fig. 12 is a process for forming a geogrid according to the present invention.

#### **Detailed Description of the Preferred Embodiments**

25 The geogrids of the present invention resist elongation, creep, and deterioration in hostile environments such as alkali environments and have higher strength to weight ratios than typical polymeric geogrids presently available. Also, the density of such geogrids is similar to that of saturated soil materials, which lessens the likelihood of movement of the geogrids when  
30 installed in saturated or supersaturated soil-reinforcing applications.

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Referring to the drawings, wherein like numerals indicate like elements throughout, there is shown Figs. 1 and 5 preferred embodiments of a geogrid for reinforcing soil material, indicated generally at 10, 510 according to the present invention.

5       The geogrid 10 comprises a first plurality of spaced-apart generally parallel members 12 which are generally coplanar. The members 12 are preferably generally elongated, each having an average length 14 which is greater than their average width 16, although the average length 14 of each of the members 12 can have a width 16 which is less than or equal to their  
10   length 14. The average length 14 of each of the members can range from about 2.5 to about 15 centimeters (cm) (about 1 to about 6 inches). The average width 16 of each of the members can range from about 1.3 to about 7.6 cm (about 0.5 to about 3 inches). For example, suitable members 12 can have a length of about 14 cm (about 5.5 inches) and a width of about 1.8 cm  
15   (about 0.7 inches). As another example, suitable members 12 can have a length of about 1 cm (about 2.5 inches) and a width of about 4.5 cm (about 1.8 inches).

Referring to Fig. 2A, the average thickness 18 of the members 12 can range from about 0.08 to about 0.25 cm (about 0.03 to about 0.1 inches).  
20   Preferably, the width 16 and thickness 18 of each member 12 varies along its length, i.e., each member 12 can be tapered such that its width 16 and thickness 18 are greater at the ends 20 thereof than at its midpoint.

In an important aspect of the present invention which will be discussed in detail below, the average width 16 and average thickness 18 of each of the  
25   members 12 of the first plurality of members are preferably less than the average width 22 and average thickness 24 of corresponding intersections 26 with respective intersecting members 28 of the second plurality of members.

Referring now to Fig. 5, the spacing 530 between adjacent members 532, 534 of at least one portion 536 of members 512 of the first plurality of  
30   members can be different from spacing between adjacent members 538, 540

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of another portion 542 of members 512 of the first plurality of members, although as shown in Fig. 1 adjacent members 12 preferably are equidistantly spaced. Preferably, the spacing 30 between adjacent members 32, 34 ranges from about 0.3 to about 1 cm (about 0.5 to about 2.5 inches).

5 Referring now to Fig. 2A, the first plurality of members 12 comprise a thermoplastic matrix material 44 reinforced with fibers 46. Suitable thermoplastic matrix materials 44 for forming the members 12 are selected from the group consisting of polyolefins, polyamides, thermoplastic polyurethanes, thermoplastic polyesters, acrylic polymers, vinyl polymers,  
10 acetals, polyaryl sulfones, polyether sulfones, polyimides, polyetherketones, polyphenylene oxides, polyphenylene sulfides and mixtures thereof.

Non-limiting examples of useful polyolefins include polyethylene, extended-chain polyethylene, polypropylene, polybutene, polyisoprene, and polypentene, polymethyl pentene, polytetrafluoroethylene and neoprene.  
15 Preferably the members 12 are formed from polyethylene, polypropylene or copolymers thereof. More preferably, the thermoplastic matrix material 44 is high density polyethylene.

Useful polyamides include nylons such as nylon 6, nylon 12, nylon 66, nylon 10 and nylon 12 such as are commercially available from DuPont.  
20 Suitable thermoplastic polyurethanes are condensation products of a polyisocyanate material and a hydroxyl-containing material such as polyol and include, for example, Estane and Texin polyurethanes which are commercially available from B.F. Goodrich of Toledo, Ohio and Bayer, respectively.

25 Thermoplastic polyesters useful in the present invention include polyethylene terephthalate and polybutylene terephthalate. Acrylic polymers useful in the present invention include polyacrylates, polyacrylamides and polyacrylonitriles such as nitrile rubber. Useful vinyl polymers include polyvinyl chloride, polyvinylidene chloride (saran), polyvinyl fluoride,

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polyvinylidene fluoride, ethylene vinyl acetate copolymers, such as Elvax which is commercially available from duPont, and polystyrenes.

Thermoplastic elastomeric materials useful as matrix materials in the present invention include styrene-butadiene rubbers, styrene-acrylonitrile (SAN) copolymers such as Lustran, which is commercially available from Monsanto of St. Louis, Missouri, styrene-butadiene-styrene (SBS) copolymers and acrylonitrile-butadiene-styrene (ABS) copolymers, such as Cycolac or Blendex, which are commercially available from GE Plastics of Pittsfield, Massachusetts.

Other components which can be included with the thermoplastic matrix material 44 are, for example, colorants or pigments, lubricants or process aids, ultraviolet light (UV) stabilizers, antioxidants, other fillers, and extenders.

The reinforcing fibers 46 have a predetermined deformation, distortion or melting temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material 44. The reinforcing fibers 46 can be present in a variety of forms, such as one or more generally continuous fibers 48 (shown in Fig. 2A and 2B), strips 50 of knitted, woven or non-woven fabric (shown in Fig. 2C), or discrete or chopped fibers 52 having an average length ranging from about 1 to about 25 mm (shown in Fig. 2D).

As shown in Fig. 4, the reinforcing fibers 46 preferably are present as one or more generally continuous uniaxial fibers 48 positioned generally parallel to a longitudinal axis 54 of the respective member.

At least a portion of the members 12 of the first plurality of members comprise fibers 46 formed from one or more materials selected from the group consisting of inorganic materials, natural materials, thermoplastic materials and combinations thereof which have a predetermined deformation, melting or decomposition temperature which is greater than the predetermined deformation or melting temperature of the thermoplastic matrix material 44. For example, if the thermoplastic matrix material is polyethylene,

suitable reinforcing fibers have a deformation temperature which is greater than that of polyethylene, such as glass fibers.

Useful inorganic fibers include glass fibers, polycrystalline fibers, such as ceramics including silicon carbide, and carbon or graphite. Preferably at least a portion of the members 12 of the first plurality of members comprise glass fibers. Glass fibers can be formed from any type of fiberizable glass composition known to those skilled in the art, and include those prepared from fiberizable glass compositions such as "E-glass", "A-glass", "C-glass", "D-glass", "R-glass", "S-glass", and E-glass derivatives that are fluorine-free and/or boron-free. Preferred glass fibers are formed from E-glass.

As used herein, the term "fiberizable" means a material capable of being formed into a generally continuous filament, fiber, strand or yarn. Such compositions and methods of making glass fibers therefrom are well known to those skilled in the art and further discussion thereof is not believed to be necessary in view of the present disclosure. If additional information is needed, such glass compositions and fiberization methods are disclosed in K. Loewenstein, The Manufacturing Technology of Glass Fibres, (3d Ed. 1993) at pages 30-44, 47-60, 115-122 and 126-135, which are hereby incorporated by reference.

Suitable natural fibers include those derived directly from animal, vegetable and mineral sources, such as cotton, cellulose, natural rubber, flax, ramie, hemp, sisal and wool.

Suitable thermoplastic fibers can be formed from a fibrous or fiberizable material prepared from natural organic polymers or synthetic organic polymers. Non-limiting examples of suitable thermoplastic materials for forming the fibers 46 include polyolefins, polyamides, thermoplastic polyurethanes, thermoplastic polyesters, acrylic polymers, vinyl polymers, acetals, polyaryl sulfones, polyether sulfones, polyimides, polyetherketones, polyphenylene oxides, polyphenylene sulfides and mixtures thereof.

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Non-limiting examples of useful polyamide fibers include nylon fibers, such as are commercially available from E.I. duPont de Nemours and Company of Wilmington, Delaware; polyhexamethylene adipamide; polyamide-imides and aramids such as KEVLAR™, which is commercially  
5 available from duPont.

Polyester fibers useful in the present invention include thermoplastic polyesters such as those formed from polyethylene terephthalate (for example DACRON™ which is commercially available from duPont and FORTREL™ which is commercially available from Hoechst Celanese Corp. of  
10 Summit, New Jersey) and polybutylene terephthalate.

Fibers formed from acrylic polymers believed to be useful in the present invention include polyacrylonitriles having at least about 35% by weight acrylonitrile units, and preferably at least about 85% by weight, which can be copolymerized with other vinyl monomers such as vinyl acetate, vinyl  
15 chloride, styrene, vinylpyridine, acrylic esters or acrylamide. A non-limiting example of a suitable acrylic polymer fiber is ORLON™, which is commercially available from duPont.

Useful polyolefin fibers are generally composed of at least 85% by weight of ethylene, propylene, or other olefins. Fibers formed from vinyl  
20 polymers believed to be useful in the present invention can be formed from polyvinyl chloride, polyvinylidene chloride (such as SARAN™, which is commercially available from Dow Plastics of Midland, Michigan), polytetrafluoroethylene, and polyvinyl alcohol (such as VINYLON™, a polyvinyl alcohol fiber which has been crosslinked with formaldehyde).

25 Fibers believed to be useful in the present invention include those discussed above, and methods for preparing and processing such fibers are discussed in the Encyclopedia of Polymer Science and Technology, Vol. 6 (1967) at pages 505-712, which is hereby incorporated by reference.

It is understood that blends or copolymers of any of the above  
30 thermoplastic materials can be used to form the reinforcing fibers 46. Also,

combinations of fibers formed from any of the above natural and thermoplastic materials can be used to form the reinforcing fibers 46.

The fibers can have a nominal filament diameter ranging from about 5.0 to about 30.0 micrometers, and preferably have a nominal filament diameter ranging from about 13.0 to about 23.0 micrometers (for glass fibers, corresponding to a filament designation of K through T). For further information regarding nominal filament diameters and designations of glass filaments, see Loewenstein at page 25, which is hereby incorporated by reference.

The fibers can be grouped into bundles to form one or more strands 56 (shown in Fig. 2C) in which the number of fibers per strand can range from about 100 to about 8000, and preferably ranges from about 1000 to about 3000. The average diameter of the strands 56 preferably ranges from about 0.25 millimeters to about 3.05 millimeters (about 0.010 to about 0.120 inches). The strands 56 can be twisted or texturized, if desired. A roving of a bundle of strands can also be used as a reinforcement, if desired.

The preferred glass reinforcing fibers 46 are coated with a coating composition. Non-limiting examples of suitable coating compositions include sizing compositions and secondary coating compositions. As used herein, the terms "size", "sized" or "sizing" refer to an aqueous coating composition applied to the filaments immediately after formation. The term "secondary coating" refers to a coating composition applied secondarily to one or a plurality of strands after the sizing composition is applied, and preferably at least partially dried. The reinforcing fibers 46 are coated with a coating composition which is compatible with the thermoplastic matrix material, i.e., the components of the coating composition facilitate wetting of the matrix material upon the fibers or fiber strands and provide adequate physical properties in the geogrid.

Preferably the sizing composition is aqueous-based and can include film-formers such as thermosetting materials and thermoplastic materials;

lubricants; coupling agents; waxes; emulsifiers and water as components. Non-limiting examples of suitable sizing compositions are disclosed in K. Loewenstein, The Manufacturing Technology of Continuous Glass Fibres, (3d Ed. 1993) at pages 237-289.

5           A preferred sizing composition includes about 78 weight percent PLURACOL V-10 polyoxyalkylene polyol (commercially available from BASF Wyandotte of Michigan); about 8 weight percent EMERY 6717 partially amidated polyethylene imine lubricant (commercially available from Henkel Corporation of Kankakee, Illinois) and about 14 weight percent A-1108  
10       aminosilane (commercially available from OSi Specialties, inc. of Danbury Connecticut).

          The sizing composition preferably comprises one or more polymeric film forming materials which are compatible with the thermoplastic matrix material. Non-limiting examples of suitable film-forming materials for use in  
15       the present invention include thermoplastic materials, thermosetting materials and mixtures thereof.

          Examples of suitable thermoplastic and thermosetting film-forming materials include acrylic polymers, aminoplasts, alkyds, polyepoxides, phenolics, polyamides, polyolefins, polyesters, polyurethanes, vinyl polymers,  
20       derivatives and mixtures thereof.

          Useful acrylic polymers include polymers or copolymers of monomers such as acrylic acid; methacrylic acid; esters of these acids such as acrylates, methacrylates, ethylacrylate, propylacrylate and butylacrylate; polyglycidyl acrylates and methacrylates; acrylamides; acrylonitriles; and copolymers with  
25       unsaturated vinyl compounds such as styrene or vinyl acetate. Non-limiting examples of suitable acrylic polymers include FULATEX® materials which are commercially available from H. B. Fuller Co. of St. Paul, Minnesota and RHOPLEX® acrylic emulsions which are commercially available from Rohm and Haas of Philadelphia, Pennsylvania.

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Useful aminoplasts include urea-formaldehyde and melamine formaldehyde. Useful epoxides polyglycidyl ethers of polyhydric alcohols such as EPON® 826 and 828 epoxy resins, which are epoxy functional polyglycidyl ethers of bisphenol A which are commercially available from Shell  
5 Chemical.

Useful polyamides include the VERSAMID products which are commercially available from General Mills Chemicals, Inc. Suitable thermoplastic polyurethanes include, for example, WITCOBOND® W-290H which is commercially available from Witco Chemical Corp. of Chicago, Illinois  
10 and RUCO 2011L which is commercially available from Ruco Polymer Corp. of Hicksville, New York. Suitable thermosetting polyurethanes include BAYBOND XW-110, which is commercially available from Bayer Corp. of Pittsburgh, Pennsylvania.

Non-limiting examples of useful vinyl polymers include RESYN 1971,  
15 RESYN 2828 and RESYN 1037 vinyl acetate copolymer emulsions which are commercially available from National Starch and Chemicals of Bridgewater, New Jersey. Other useful vinyl polymers include polyvinyl pyrrolidones such as PVP K-15, PVP K-30, PVP K-60 and PVP K-90 which are commercially available from ISP Chemicals of Wayne, New Jersey.

20 Non-limiting examples of useful polyolefins include polypropylene and polyethylene materials such as the polypropylene emulsion RL-5440, which is commercially available from Sybron Chemicals of Birmingham, New Jersey, and Polyemulsion CHEMCOR 43C30, which is commercially available from Chemical Corp. of America. Non-limiting examples of useful polyester  
25 materials include RD-847A polyester resin which is commercially available from Borden Chemicals of Columbus, Ohio, STYPOL polyesters which are commercially available from Cook Composites and Polymers of Port Washington, Wisconsin and NEOXIL polyesters which are commercially available from DSM B.V. of Como, Italy. Thermoplastic polyesters useful in  
30 the present invention include ethylene adipates (such as DESMOPHEN 2000)

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and ethylene butylene adipates (such as DESMOPHEN 2001KS), both of which are commercially available from Bayer.

The amount of film-forming material can be about 1 to about 90 weight percent of the sizing composition on a total solids basis, and is preferably  
5 about 60 to about 80 weight percent.

The sizing composition preferably comprises one or more glass fiber lubricants. Useful glass fiber lubricants include cationic, non-ionic or anionic lubricants and mixtures thereof. Generally, the amount of fiber lubricant can be about 1 to about 25 weight percent of the sizing composition on a total  
10 solids basis.

Non-limiting examples of such fiber lubricants include amine salts of fatty acids, alkyl imidazoline derivatives, acid solubilized fatty acid amides, condensates of a fatty acid and polyethylene imine and amide substituted polyethylene imines, such as EMERY® 6717, a partially amidated  
15 polyethylene imine commercially available from Henkel Corporation of Kankakee, Illinois.

The sizing composition preferably also comprises one or more coupling agents typically having dual functionality. Each metal or silicon atom has attached to it one or more groups which can react or compatibilize with the  
20 glass filament surface and/or the components of the sizing composition. As used herein, the term "compatibilize" with respect to coupling agents means that the groups are chemically attracted, but not bonded, to the glass filament surface and/or the components of the sizing composition, for example by polar, wetting or solvation forces. Examples of suitable functional organo  
25 silane coupling agents include A-187 gamma-glycidoxypolytrimethoxysilane, A-174 gamma-methacryloxypropyltrimethoxysilane and A-1100 gamma-aminopropyltriethoxysilane silane coupling agents, each of which are commercially available from OSi Specialties, Inc. of Tarrytown, New York. The organo silane coupling agent can be at least partially hydrolyzed with  
30 water prior to application to the glass filaments, preferably at about a 1:3

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stoichiometric ratio or, if desired, applied in unhydrolyzed form. The amount of coupling agent can be 1 to about 10 weight percent of the sizing composition on a total solids basis.

The sizing composition can comprise one or more emulsifying agents  
5 for emulsifying components of the sizing composition, such as  
polyoxyalkylene block copolymers, ethoxylated alkyl phenols,  
polyoxyethylene octylphenyl glycol ethers, ethylene oxide derivatives of  
sorbitol esters and polyoxyethylated vegetable oils. Generally, the amount of  
emulsifying agent can be about 1 to about 20 weight percent of the sizing  
10 composition on a total solids basis.

The sizing composition can also include one or more aqueous  
dispersible or soluble plasticizers to improve flexibility, such as CARBOWAX  
400, a polyethylene glycol which is commercially available from Union  
Carbide of Danbury, Connecticut. The amount of plasticizer is more  
15 preferably less than about 5 weight percent of the sizing composition on a  
total solids basis.

Fungicides, bactericides and anti-foaming materials and organic  
and/or inorganic acids or bases in an amount sufficient to provide the  
aqueous sizing composition with a pH of about 2 to about 10 can also be  
20 included in the sizing composition. Water (preferably deionized) is included  
in the sizing composition in an amount sufficient to facilitate application of a  
generally uniform coating upon the strand. The weight percentage of solids  
of the sizing composition generally can be about 4 to about 20 weight  
percent. For a discussion of application of sizings to fibers and drying  
25 conditions, see Loewenstein at pages 165-172 and 219-222, which are  
hereby incorporated by reference. The sizing is typically present on the  
filaments in an amount ranging from about 0.3 percent to about 1.5 percent  
by weight after drying. After drying the sized glass filaments can be gathered  
together into bundles or strands of generally parallel fibers or roving and can  
30 be further treated with the secondary coating composition which is different

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from the sizing composition. The secondary coating composition can include one or more of the components of the sizing composition discussed above, and is preferably aqueous-based.

Examples of useful sized and secondarily coated strands include  
5 HERCUFLEX™ fiber glass strands which are commercially available from PPG Industries, Inc. of Pittsburgh, Pennsylvania. See "HERCUFLEX™ Strand: The Applications Are Endless", a technical bulletin of PPG Industries (about 1990), which is hereby incorporated by reference. HERCUFLEX™ fiber glass strands can be sized and coated with secondary coating  
10 compositions such as are disclosed in U.S. Patents Nos. 4,762,750 and 4,762,751.

Referring now to Fig. 1, the geogrid 10 also comprises a second plurality of spaced-apart generally parallel thermoplastic cross-members 58 positioned adjacent to and forming a plurality of intersections 26 with at least  
15 a portion 36 of the first plurality of members 12. The intersecting members 12, 58 form a grid pattern preferably having a plurality of openings 60 therein. As may be appreciated by those skilled in the art, the intersecting members 12, 58 need not intersect perpendicularly to one another. The intersecting angle can range from about 30° to about 120°, although an angle of about  
20 90° is preferred. The length 61 of the opening can range from about 2.5 to about 15.2 cm (about 1 to about 6 inches) and its width 63 can range from about 1.3 to about 7.6 cm (about 0.5 to about 3 inches).

The cross-members 58 of the second plurality of members are generally coplanar and can be configured and have dimensions similar to the  
25 members 12 discussed above. The cross-members 58 generally have an average thickness 60 which is less than or equal to the average thickness 24 of the corresponding intersections 26. Referring to Fig. 3a, the average thickness 60 of the members 58 can range from about 0.25 to about 0.8 cm (about 0.1 to about 0.3 inches).

The cross-members 58 preferably have an average overall thickness 60 (shown in Figs 3a and 3b) which is greater than an average overall thickness 24 of respective intersecting members 28 of the first plurality of members 12. For example, if the average thickness of the first plurality of members 12 is about 0.13 cm (about 0.05 inches), the average thickness of the cross-members 58 can be about 0.4 cm (about 0.15 inches).

Preferably the intersections 26 and members 58 of the second plurality of members have the same generally uniform thickness, as shown in Figs. 6 and 7. The average thickness 24 of an intersection 26 of the plurality of intersections is greater than the average thickness of a corresponding member 12 of the first plurality of members which is adjacent to the intersection 26. The average thickness 24 of an intersection 26 of the plurality of intersections ranges from about 0.25 to about 1.3 cm (about 0.1 to about 0.5 inches).

The thermoplastic cross-members 58 can be formed from any of the thermoplastic matrix materials discussed above as suitable for forming the members 12, and are preferably formed from the same thermoplastic matrix material as the members 12. At least a portion of the cross-members 58 of the second plurality of members can be reinforced with fibers 62 having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material. The fibers 62 can be formed from and configured similarly to the reinforcing fibers 46 discussed above, and are preferably glass fibers.

The geogrid 10 of the present invention can be formed in a variety of ways. For example, the reinforced geogrid 10 can be formed by introducing reinforcing fibers 46 and/or 62 during formation of plastic mesh structures such as are disclosed in U.S. Patents Nos. 4,374,798; 4,756,946; 5,156,495 and 5,419,659, which are hereby incorporated by reference. Chopped fibers can be combined with the thermoplastic matrix material by, for example, extrusion compounding to form a sheet prior to uniaxial or biaxial stretching of

the perforated or indented sheet to form the geogrid. Suitable conditions and parameters for stretching the thermoplastic materials to form the geogrid structures of the present invention are similar to those disclosed in U.S. Patents Nos. 4,374,798; 4,756,946; 5,156,495 and 5,419,659.

5 Referring to Fig. 12, preferably, generally continuous glass fibers, fabrics and/or chopped fibers 1246 are fed with the thermoplastic matrix material 1244 into a cross-head extrusion die 1247 to coat the fibers or fabrics and form the first plurality of members 1212. One or more of the second plurality of cross-members 1258 can include chopped, continuous  
10 reinforcing fibers and/or fabrics. Preferably, the second plurality of cross-members 1258 are preformed (for example by a cross-head extrusion process 1259), positioned adjacent to respective first plurality of members 1212, and heated to partially deform and bond the first plurality of members 1212 to the second plurality of cross-members 1258, for example by passing  
15 the members 1212, 1258 over one or more heated calendaring rolls 1260, to form the geogrid 1200. Alternatively, if the first plurality of members 12 and/or second plurality of members 58 are in a softened state, bonding can be accomplished without external heating of the members 12 and/or 58. In another alternative embodiment, an adhesive agent can be use to bond the  
20 intersecting members 12, 58.

While the geogrid of the present invention can be manufactured in any width or in any length, typically the geogrid is formed to have a width of about 0.9 to about 4.6 meters (about 3 to about 15 feet) and severed into lengths of about 30.5 to about 46 meters (about 100 to about 150 feet) for ease of  
25 installation.

Referring now to Figs. 8 and 9, geosynthetic composites 100, 200 can be formed from the geogrid 110, 210 of the present invention and one or more geosynthetic materials 112, 212 positioned coextensive with at least a portion of and positioned adjacent to a side 114, 214 of the geogrid 110, 210  
30 wherein the second geosynthetic material 112, 212 is different in

configuration and/or components from the geogrid 110, 210. The second geosynthetic material 112, 212 can be a film, clay or synthetic liner and/or a geosynthetic fabric, such as a nonwoven scrim material 116 or woven fabric 216.

5           The second geosynthetic material 112 can be permeable, semi-permeable or impermeable to water or other liquids. The second geosynthetic material 112 can be attached to the geogrid by any means known in the art, such as mechanical forms of attachment (i.e., knitting, stitching, etc.), chemical forms of attachment (i.e., bonding agents such as  
10 adhesives) or combinations thereof. The second geosynthetic material 112 can be attached to a portion or all of the geogrid 110.

          The geogrids 310, 410 of the present invention are suitable for reinforcing a wide variety of soil materials to form reinforced soil composites 300, 400 (shown in Figs. 10 and 11) useful in many engineering applications.  
15 As used herein, "soil material" means earthen material including but not limited to one or more of the following components: inorganic mineral soils such as gravel, sand, silt, clay and mixtures thereof, organic materials, metallic waste materials and fossil fuel waste materials.

          Such organic materials can include those which were naturally  
20 deposited during formation of the inorganic mineral soil. Non-limiting examples of such organic materials include one or more of the following: decomposing animal and vegetative matter, sewer spill off, oil products and derivatives thereof. While not preferred, the soil material can comprise one or more metallic waste materials, for example heavy metals such as chromium  
25 or lead. If such metallic waste materials are present, it is preferred that the soil material include one or more additives for inhibiting migration of such metallic waste materials from the soil material into the surrounding environment.

          The soil material can be formed from an aqueous soil mixture obtained  
30 by excavating dredge material from the floor of a body of water, such as a

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river, lake, channel or preferably from an ocean. Dredge material generally comprises one or more of the mineral soils and water as discussed in detail above. Dredge material preferably also comprises one or more organic materials such as are discussed above.

5 Referring now to Fig. 10, there is shown a cross section of a side elevational view of a reinforced soil composite 300 in the form of a slope 314 which includes layers 316 of soil material 318 having a geogrid 310 in accordance with the present invention disposed therebetween. Tensile load is applied on the soil composite in the direction of arrow 320, by a shear line  
10 322, shown in phantom in Fig. 10. In the soil composite shown in Fig. 10, geogrid elongation, and hence creep, is directed along a line in the direction of arrow 320. Therefore, it is preferable that the first plurality of members are oriented along a line parallel to the direction of arrow 320, and that the first plurality of members of the geogrid 310 include glass fibers to minimize or  
15 prevent creep, thus reinforcing the slope 314 and providing stabilization of the supporting soil material 318.

Referring now to Fig. 11, there is shown a cross section of a side elevational view of a landfill 400. Landfill 400 includes geogrid 410 of the present invention which includes a second geosynthetic material 414 which is  
20 impermeable to water. The geogrid 410 also prevents elongation and creep by orienting reinforcing fibers along the directions of tensile load and bridges voids 412 to prevent collapse of the surface of the landfill.

One skilled in the art would understand that the geogrids of the present invention can be used in a wide variety of soil reinforcement applications,  
25 including geotechnical engineering applications such as load bearing applications, road and building foundations, slopes, fill, artificial coastlines and islands, levies, sound barriers, erosion control, soil stabilization and vegetation support.

It will be appreciated by those skilled in the art that changes could be  
30 made to the embodiments described above without departing from the broad

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inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modification which are within the spirit and scope of the invention, as defined by the appended claims.

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## WE CLAIM:

1. A geogrid for reinforcing soil material, the geogrid comprising:
  - (a) a first plurality of spaced-apart generally parallel members  
5 comprising a thermoplastic matrix material reinforced with fibers having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material;  
and
  - (b) a second plurality of spaced-apart generally parallel  
10 thermoplastic cross-members positioned adjacent to and forming a plurality of intersections with at least a portion of the first plurality of strands,  
wherein average thickness of an intersection of the plurality of intersections is greater than average thickness of a corresponding member of the first plurality of members which is adjacent to the intersection.
- 15 2. The geogrid according to claim 1, wherein the members of the first plurality of members are generally coplanar.
3. The geogrid according to claim 1, wherein spacing between  
20 adjacent members of at least one portion of members of the first plurality of members is different from spacing between adjacent members of another portion of members of the first plurality of members.
4. The geogrid according to claim 1, wherein the fibers are present  
25 as discrete fibers having an average length ranging from about 1 to about 25 mm.
5. The geogrid according to claim 1, wherein the fibers are present  
as generally continuous fibers.

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6. The geogrid according to claim 5, wherein generally continuous fibers positioned within a respective member of the first plurality of members are generally parallel to a longitudinal axis of the respective member.

5 7. The geogrid according to claim 1, wherein the fibers are present as a fabric.

8. The geogrid according to claim 1, wherein at least a portion of the members of the first plurality of members comprise fibers formed from  
10 materials selected from the group consisting of inorganic materials, natural materials, thermoplastic materials and combinations thereof

9. The geogrid according to claim 8, wherein at least a portion of the members of the first plurality of members comprise glass fibers.

15

10. The geogrid according to claim 1, wherein the first plurality of members are formed from a thermoplastic matrix material selected from the group consisting of polyolefins, polyamides, thermoplastic polyurethanes, thermoplastic polyesters, acrylic polymers, vinyl polymers, acetals, polyaryl  
20 sulfones, polyether sulfones, polyimides, polyetherketones, polyphenylene oxides, polyphenylene sulfides and mixtures thereof.

11. The geogrid according to claim 1, wherein the cross-members of the second plurality of members are generally coplanar.

25

12. The geogrid according to claim 1, wherein a cross-member of the second plurality of members has an average overall thickness which is greater than an average overall thickness of an intersecting member of the first plurality of members.

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13. The geogrid according to claim 1, wherein spacing between adjacent cross-members of at least one portion of the cross-members of the second plurality of members is different from spacing between adjacent cross-members of another portion of the cross-members of the second plurality of members.

14. The geogrid according to claim 1, wherein the second plurality of thermoplastic cross-members are formed from a thermoplastic matrix material selected from the group consisting of polyolefins, polyamides, thermoplastic polyurethanes, thermoplastic polyesters, acrylic polymers, vinyl polymers, acetals, polyaryl sulfones, polyether sulfones, polyimides, polyetherketones, polyphenylene oxides, polyphenylene sulfides and mixtures thereof.

15. The geogrid according to claim 1, wherein at least a portion of the cross-members of the second plurality of members are formed from a thermoplastic matrix material reinforced with fibers having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material.

20

16. The geogrid according to claim 15, wherein the fibers of the second plurality of members are present as discrete fibers having an average length ranging from about 1 to about 25 mm.

17. The geogrid according to claim 15, wherein the fibers of the second plurality of members are present as generally continuous fibers.

18. The geogrid according to claim 17, wherein generally continuous fibers positioned within a respective cross-member of the second

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plurality of members are generally parallel to a longitudinal axis of the respective cross-member.

19. The geogrid according to claim 15, wherein the fibers of the  
5 second plurality of members are present as a fabric.

20. The geogrid according to claim 15, wherein at least a portion of  
the cross-members of the second plurality of members comprise fibers  
formed from materials selected from the group consisting of inorganic  
10 materials, natural materials, thermoplastic materials and combinations thereof

21. The geogrid according to claim 20, wherein at least a portion of  
the cross-members of the second plurality of members comprise glass fibers.

15 22. A geosynthetic composite comprising:  
(a) a geogrid for reinforcing soil material, the geogrid comprising:  
(i) a first plurality of spaced-apart generally parallel  
members comprising a thermoplastic matrix material reinforced  
with fibers having a predetermined deformation temperature  
20 which is greater than a predetermined deformation temperature  
of the thermoplastic matrix material;  
(ii) a second plurality of spaced-apart generally parallel  
thermoplastic cross-members positioned adjacent to and  
forming a plurality of intersections with at least a portion of the  
25 first plurality of strands,  
wherein average thickness of an intersection of the plurality of  
intersections is greater than average thickness of a corresponding  
member of the first plurality of members which is adjacent to the  
intersection; and

30

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(b) a second geosynthetic material coextensive with at least a portion of and positioned adjacent to a side of the geogrid, wherein the second geosynthetic material is different from the geogrid.

5           23. The geosynthetic composite according to claim 22, wherein the second geosynthetic material is selected from the group consisting of a film, liner and a geosynthetic fabric.

10           24. A reinforced soil composite comprising:

(a) soil material; and

(b) a geogrid for reinforcing the soil material to form a reinforced soil composite, the geogrid comprising:

15           (i) a first plurality of spaced-apart generally parallel members comprising a thermoplastic matrix material reinforced with fibers having a predetermined deformation temperature which is greater than a predetermined deformation temperature of the thermoplastic matrix material; and

20           (ii) a second plurality of spaced-apart generally parallel thermoplastic members positioned adjacent to and forming a plurality of intersections with at least a portion of the first plurality of strands,

25           wherein average thickness of an intersection of the plurality of intersections is greater than average thickness of a corresponding member of the first plurality of members which is adjacent to the intersection.

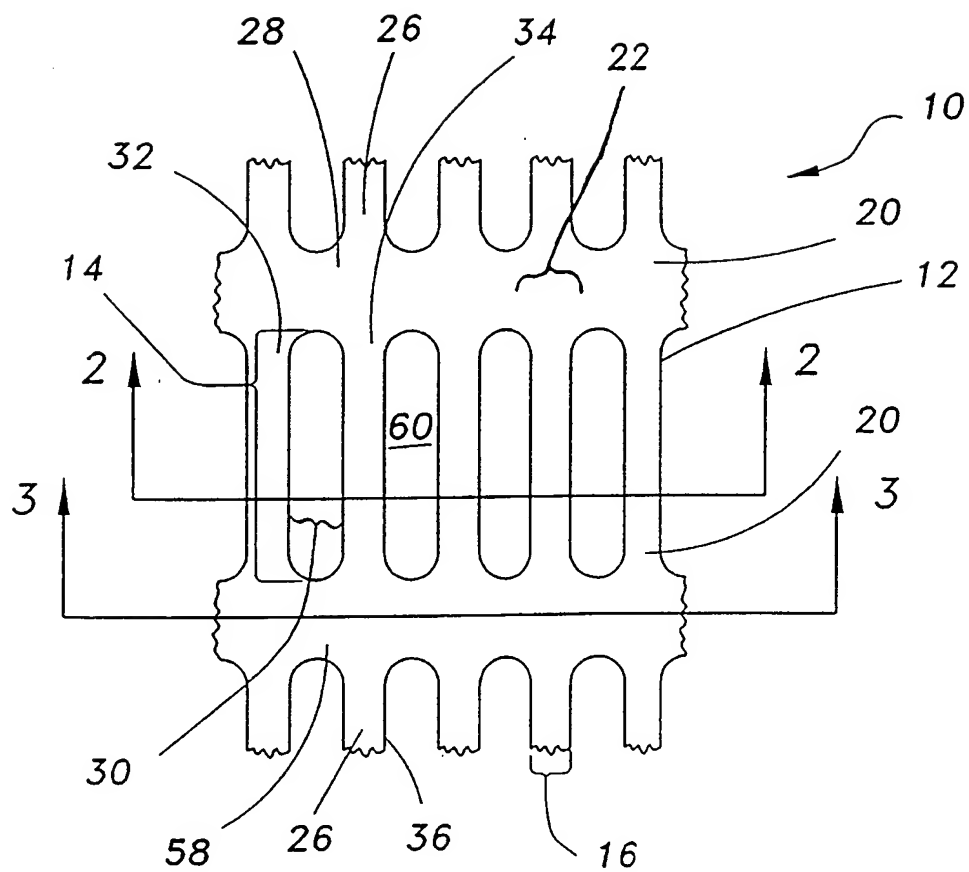


FIG. 1

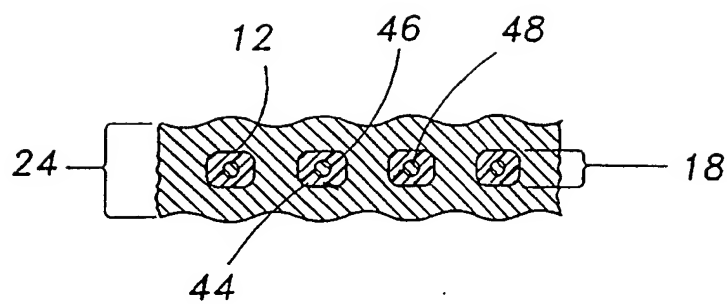


FIG. 2A

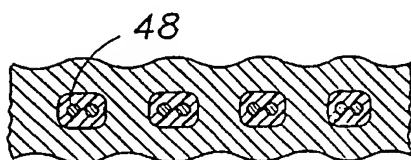


FIG. 2B

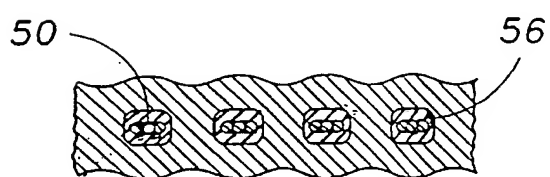


FIG. 2C

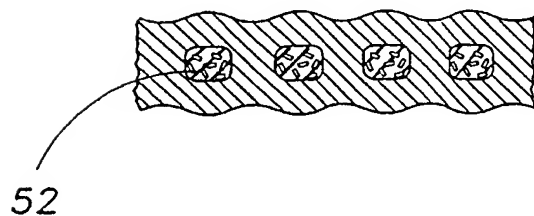


FIG. 2D

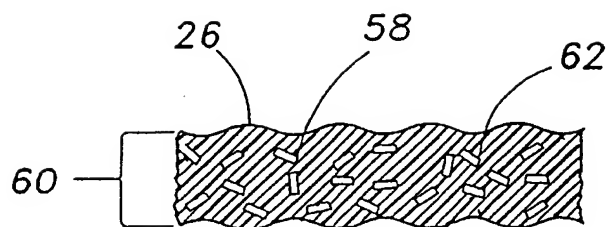


FIG. 3A

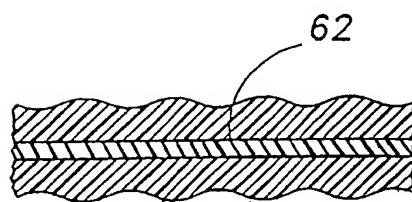


FIG. 3B

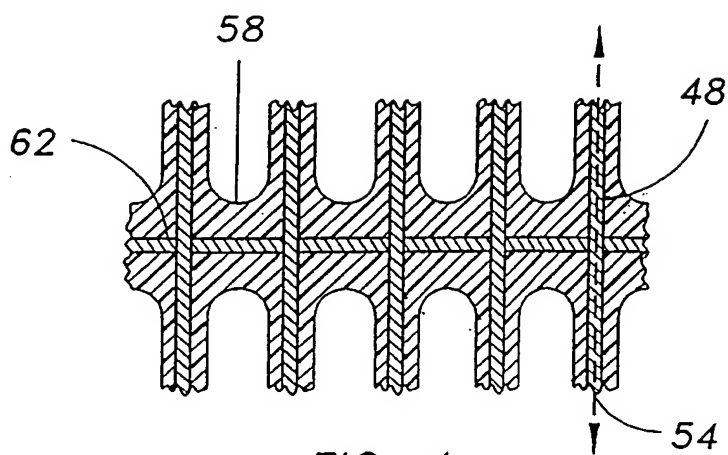


FIG. 4

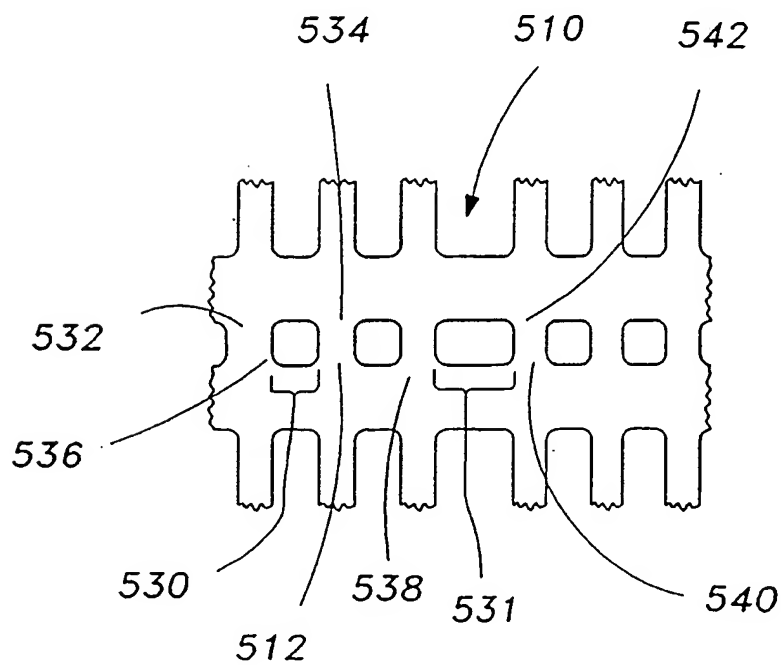


FIG. 5

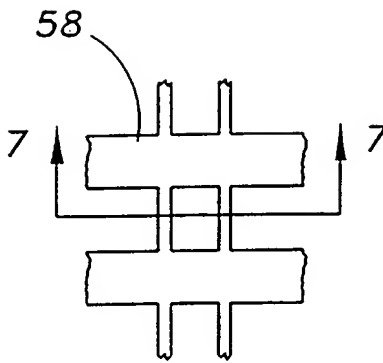


FIG. 6

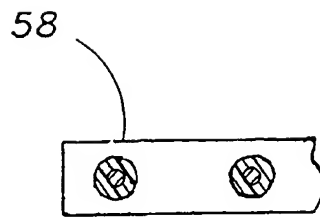


FIG. 7

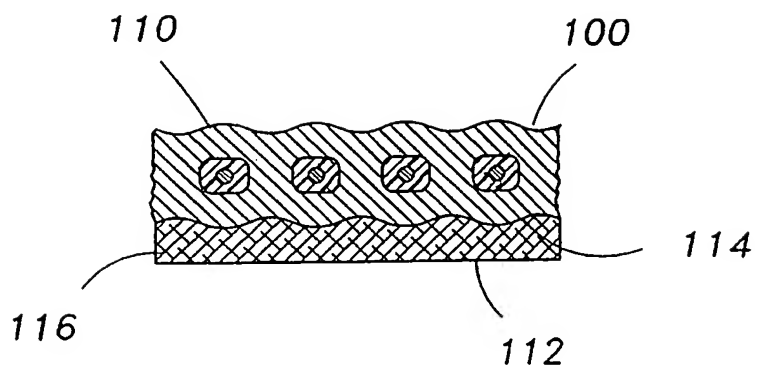


FIG. 8

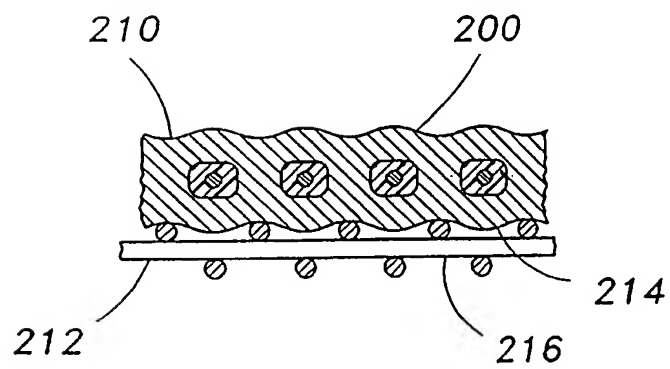


FIG. 9

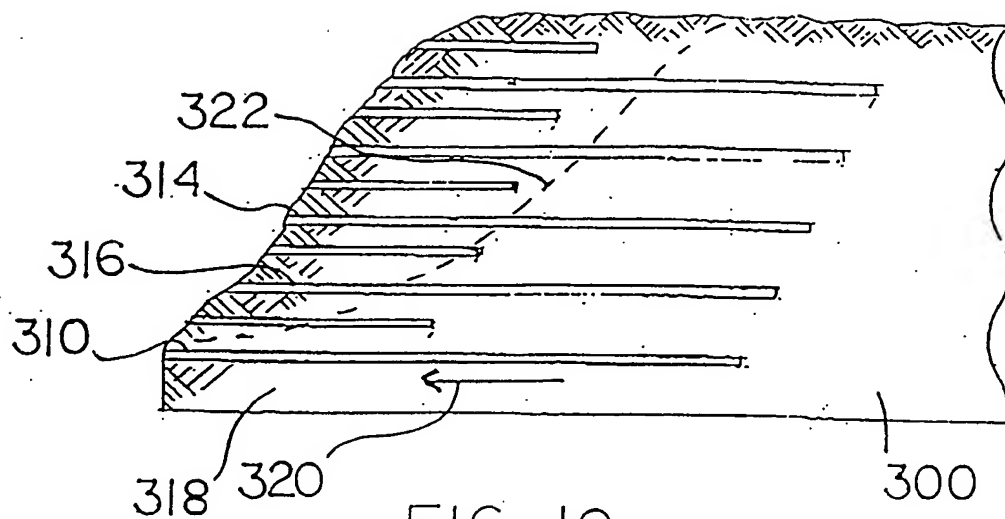


FIG. 10

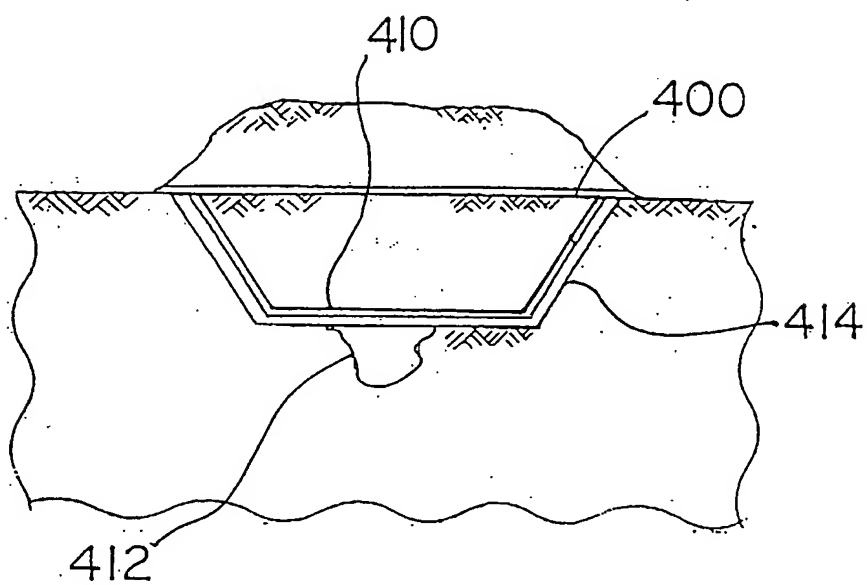


FIG. 11

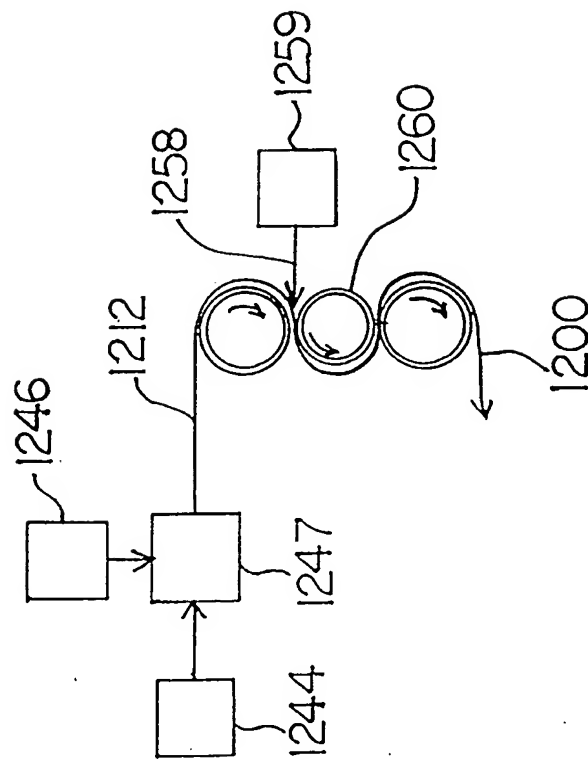


FIG. 12

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/25654

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 E02D29/02 D01F8/14

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 E02D D01F D01D B28D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 045 377 A (AMATA CHARLES D) 3 September 1991  see the whole document ---	1-6, 8-18, 20-22
A	EP 0 773 311 A (HOECHST CELANESE CORP) 14 May 1997 see the whole document ---	1,4-10, 14-22
A	US 4 762 750 A (GIRGIS MIKHAIL M ET AL) 9 August 1988 cited in the application see the whole document ---	1,21,22
A	US 4 756 946 A (MERCER FRANK B) 12 July 1988 cited in the application see the whole document ---	1-3, 10-15, 22-24
-/--		

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search

18 March 1999

Date of mailing of the international search report

24/03/1999

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Authorized officer

Tellefsen, J

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 98/25654

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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